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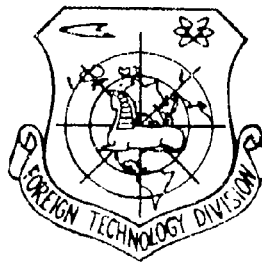
FOREIGN TECHNOLOGY DIVISION



ATMOSPHERIC TURBULENCE

by

V. I. Tatarskiy



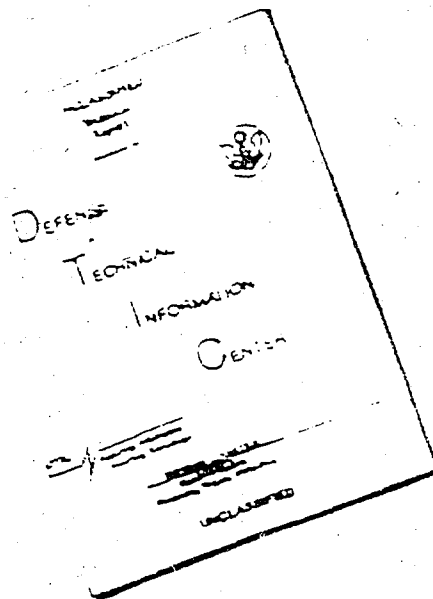
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ATMOSPHERIC TURBULENCE

By: V. I. Tatarskiy

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| ABSTRACT (U) In this conversational approach to the effects of atmospheric turbulence, the atmosphere is compared to a tube filled with water containing some visible particles which can be observed as they are affected by turbulent motion. The effects of turbulence are seen in the action of an airplane when pressure on the wings is uneven, causing a bumpy ride. Turbulence has a great effect in preventing heavy gases, smoke, radioactive waste, and such substances from collecting at the surface of the earth. It is also seen to have great influence on the heat cycle, refraction, propagation of radio waves, and astronomical observations, causing stars to appear to twinkle. A brief summary of outstanding scholars and studies in the field of atmospheric turbulence is given, and the two-volume monograph "Statistical Hydromechanics" by A. S. Monin and A. M. Yaglom is cited. Orig. art. has: 3 figures. | | | | |

U. S. BOARD ON GEOGRAPHIC NAMES transliteration SYSTEM

| Block | Italic | Transliteration | Block | Italic | Transliteration |
|-------|------------|-----------------|-------|------------|-----------------|
| А а | <i>А а</i> | A, a | Р р | <i>Р р</i> | R, r |
| Б б | <i>Б б</i> | B, b | С с | <i>С с</i> | S, s |
| В в | <i>В в</i> | V, v | Т т | <i>Т т</i> | T, t |
| Г г | <i>Г г</i> | G, g | У у | <i>У у</i> | U, u |
| Д д | <i>Д д</i> | D, d | Ф ф | <i>Ф ф</i> | F, f |
| Е е | <i>Е е</i> | Ye, ye; E, e* | Х х | <i>Х х</i> | Kh, kh |
| Ж ж | <i>Ж ж</i> | Zh, zh | Ц ц | <i>Ц ц</i> | Ts, ts |
| З з | <i>З з</i> | Z, z | Ч ч | <i>Ч ч</i> | Ch, ch |
| И и | <i>И и</i> | I, i | Ш ш | <i>Ш ш</i> | Sh, sh |
| Й й | <i>Й й</i> | Y, y | Щ щ | <i>Щ щ</i> | Shch, shch |
| К к | <i>К к</i> | K, k | Ъ ъ | <i>Ъ ъ</i> | " |
| Л л | <i>Л л</i> | L, l | Ы ы | <i>Ы ы</i> | Y, y |
| М м | <i>М м</i> | M, m | Ь ь | <i>Ь ь</i> | ' |
| Н н | <i>Н н</i> | N, n | Э э | <i>Э э</i> | E, e |
| О о | <i>О о</i> | O, o | Ю ю | <i>Ю ю</i> | Yu, yu |
| П п | <i>П п</i> | P, p | Я я | <i>Я я</i> | Ya, ya |

* ye initially, after vowels, and after ъ, ь; e elsewhere.
 When written as ѣ in Russian, transliterate as yѣ or ѣ.
 The use of diacritical marks is preferred, but such marks
 may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH
DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

| Russian | English |
|-----------|--------------------|
| sin | sin |
| cos | cos |
| tg | tan |
| ctg | cot |
| sec | sec |
| cosec | csc |
| sh | sinh |
| ch | cosh |
| th | tanh |
| cth | coth |
| sch | sech |
| csch | csch |
| arc sin | sin ⁻¹ |
| arc cos | cos ⁻¹ |
| arc tg | tan ⁻¹ |
| arc ctg | cot ⁻¹ |
| arc sec | sec ⁻¹ |
| arc cosec | csc ⁻¹ |
| arc sh | sinh ⁻¹ |
| arc ch | cosh ⁻¹ |
| arc th | tanh ⁻¹ |
| arc cth | coth ⁻¹ |
| arc sch | sech ⁻¹ |
| arc csch | csch ⁻¹ |
| <hr/> | |
| rot | curl |
| lg | log |

ATMOSPHERIC TURBULENCE

V. I. Tatarskiy, Doctor of Physical and
Mathematical Sciences

Twinkling of stars and "bumping" of an aircraft the propagation of smoke, and the possibility of reception of distant television transmissions are all effects connected with atmospheric turbulence.

Apparently, everyone who has flown on an aircraft at some time has felt one of the unpleasant consequences of atmospheric turbulence - "bumping."

Atmospheric turbulence also appears in many other phenomena, at first glance, having nothing in common. With it are connected such effects as heating of the atmosphere by solar rays, its contamination by different impurities, the flickering of stars, and cases of anomalously good conditions of propagation of ultrashort radio waves, by means of which television transmissions are made.

What is turbulence?

Imagine a straight glass tube through which water flows. If in the initial part of the tube we mix in particles of some brightly colored substance, using such a substance that the particles do not rise, but also do not sink, it will be possible to observe the motion and trajectory of these particles. It turns out that if the

speed of flow of the water is not very great, the trajectories of each particle will be rectilinear. If we release the particles in the same place of the tube's cross section, they will move on the same trajectory. Such motion is called laminar. But if we increase the speed of the water, starting from a certain "critical" speed (this speed is less, the greater the diameter of the tube) the motion changes in character. Trajectories of motion of particles start to be distorted: particles move not only along the axis of the tube, but also in the transverse direction. However, the most basic distinction between such turbulent flow and laminar flow consists in that if we always release the colored particles at the same place in the tube, their trajectories will appear different, and it is impossible to predict just what they will be. The trajectories of motion of liquid in turbulent flow become "random," and particles can go to any point in the tube. If, however, we watch the flow at some fixed point, we find that the magnitude and direction of speed go through disordered changes - fluctuations.



Schematic representation of the refraction of a light ray in turbulent atmosphere.

The atmosphere can be compared to a huge "tube" through which air flows. Since the "diameter" of this tube is very great, for practically all wind speeds which are observed in nature the motion of air has turbulent character.

What then is the result of atmospheric turbulence? Let us follow the flight of an aircraft. The lift acting on its wings depends on the speed of the incident air stream. During flight it crosses regions of space in which turbulent fluctuations cause wind

speed to be different. Therefore the lifting force acting on the aircraft also varies, as a result of which it experiences "bumping."

Let us consider certain other effects connected with turbulence. After putting sugar in a glass of tea, we always stir it. Why? If the tea were not stirred, dissolution of the sugar would take place extraordinarily slowly, as would the spreading of sweet solution to other parts of the liquid. Dissolving molecules of sugar collide with surrounding molecules of water, and it is very difficult for them to penetrate further from that place at which they were "released." By mixing the solution we can quickly distribute the sugar in the glass more or less evenly over the entire volume.

Analogous processes occur in the atmosphere. Here the mixing is the result of turbulence, since the trajectories of motion of separate small masses of air are of extraordinarily intricate character and are found in different parts of the atmosphere. The described method of propagation of impurities is called turbulent diffusion. Turbulent diffusion is of tremendous importance in our life. If it did not exist, the atmosphere would have quite another structure than is observed in nature. Heavy gases, such as carbon dioxide and argon, of which there is comparatively little in the atmosphere, would be concentrated at the earth's surface, so that the gas composition of that part of the atmosphere in which we live would be quite different, which would be reflected significantly on our life. Furthermore, numerous impurities which contaminate the atmosphere (smoke, waste from the chemical industry, radioactive impurities, etc.) also would be concentrated at the earth's surface. And only as a result of continuous turbulent mixing of the atmosphere is its chemical composition practically constant up to heights of over one hundred kilometers.

Turbulent diffusion is also of great importance to the thermal balance of the atmosphere. Solar rays are practically unabsorbed by the atmosphere and heat the earth's surface. The heated surface gives up part of the heat as a result of intrinsic emission (any heated body radiates at least weakly,). But a considerable part of

the heat radiation of the earth's surface is caused by turbulence. Masses of air in contact with the earth's surface are heated and upon reaching high altitudes give up their heat to higher layers of the atmosphere.



Condenser microphone with a area of about one square meter, with the help of which investigations of scattering of sound by turbulent heterogeneities of the atmosphere were conducted. The second such transducer was used as a sound radiator. (The instruments were developed at the Institute of Atmospheric Physics of the Academy of Sciences of the USSR).

Turbulence also causes fluctuation (disordered changes) in the temperature of the atmosphere. Its lower layers have higher temperature than those above. Owing to turbulent mixing, separate small masses of air pass from one height to another and bring with them their "own" value of temperature, which differs from that of the surrounding air. As a result heterogeneities of temperature of the atmosphere appear. Heterogeneities of humidity likewise appear.

With heterogeneities of temperature and humidity are connected heterogeneities of the refractive index of air. The refractive index characterizes the propagation velocity of light and radio waves in a

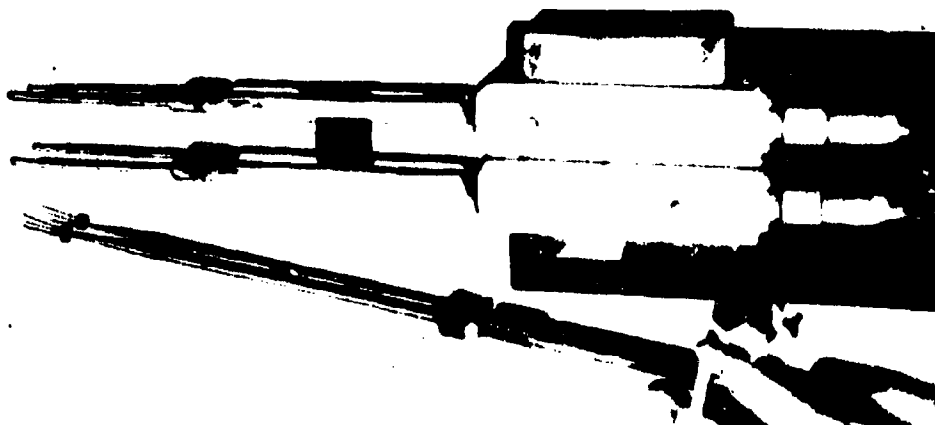
substance and depends on temperature and atmospheric humidity. In turbulent atmosphere the refractive index changes chaotically from point to point. But such change of the refractive index is equivalent to the fact that in the atmosphere collecting and dispersing lenses are scattered. From an optical standpoint a lens is simply a part of space in which the refractive index differs from that of the environment. Let us trace a ray of light piercing the atmosphere. In its path it encounters a great number of "random lenses," as a result of which either focusing or defocusing of the ray occurs. The "lens" are shifted by the wind, so that the ray at various moments of time passes through different heterogeneities. As a result of this the intensity of light reaching the eye or a telescope changes in a disordered manner. This is the well-known phenomenon of twinkling of stars. Distant ground sources of light twinkle especially strongly since in this case rays pass along the surface of the earth, where turbulence is the most intense.

The described "optical instability" of the atmosphere so strongly hinders astronomical observations that recently attempts were undertaken to conduct these observations by lifting telescopes by balloon to high altitudes. The optical instability of the atmosphere can also be a great hinderance during the use of lasers as means of communication.

Such, in brief, are certain effects of atmospheric turbulence. As can be seen, many of these effects are very unpleasant, and it is necessary to combat them. For example, during the designing of aircraft or tall structures one must consider the possibility of the appearance of harmful vibrations caused by turbulence. It is necessary to understand to eliminate interference affecting communication lines using lasers. For this it is necessary to know the rather subtle properties of atmospheric turbulence.

Investigation of turbulence was started in the last century by O. Reynolds and was continued by J. Taylor, A. A. Fridman and L. V. Keller, L. Prandtl, T. Karman, and many other scientists. A very great contribution to the study of turbulence has been made by the

works of Soviet scientists. In our country work on the theory of turbulence was started in the twenties by A. A. Fridman and L. V. Keller. An especially great change in this area of science took place in 1941, when A. N. Kolmogorov, L. D. Landau, and A. M. Obukhov explained the most significant peculiarities of turbulence. This work obtained wide recognition among scientists of the entire world. Now the study of turbulence and phenomena connected with it continues in many scientific establishments both in our country and abroad. Although very much in this area has already become clear the theory of turbulence is not yet complete, and very extensive work must be done in analysis of this phenomenon.



Transducers of the acoustic anemometer and thermometer. The upper instrument constitutes two pairs of miniature microphones and ultrasonic radiators (cylinders with diameter of approximately 2 mm - in the upper left part of the photograph). The instrument measures the speed of sound and from this determined wind velocity with an accuracy of a few centimeters per second. Below is the pickup of a low-inertia resistance thermometer. (The instruments were developed at the Institute of Atmospheric Physics of the Academy of Sciences of the USSR).

At the Institute of Atmospheric Physics of the Academy of Sciences of the USSR experimental and theoretical research has been conducted for several years on turbulence and its influence on propagation of light and radio waves in the atmosphere. Great successes have been achieved in investigation of turbulence in the

layer of the atmosphere, where its connection with meteorological conditions has already been well studied. Results of long-term investigations of turbulence are summarized in the fundamental two-volume monograph "Statistical Hydromechanics," written by the institute scientists A. S. Monin and A. M. Yaglom.